assignments are the minimum necessary to achieve all these important social and business objectives.

Many PCS operators will have to coexist with microwave operations for an indefinite period. An impressive array of quantitative research concludes that, at least in the 1850-1970 MHz band, 40 MHz assignments present the greatest opportunity for spectrum sharing between microwave and PCS systems.

In addition to being able to commence service quickly, to compete effectively, new PCS operators' infrastructure costs must be on par with those of competing cellular systems for comparable levels of coverage and capacity. To achieve such comparability, however, the very significant differences in the physical properties of the cellular and PCS frequency bands must be mitigated. As demonstrated conclusively above, the inherent inferiority of 1800 MHz can be mitigated by assigning each PCS operator significantly more spectrum than the 25 MHz assigned currently to cellular operators. Although PCS assignments as large as 100 MHz might be necessary to establish true equivalence between cellular and PCS in terms of cost, coverage and capacity, 40 MHz PCS assignments represent a reasonable tradeoff between system economy, diversity and competition.

Finally, despite the political attractiveness of allowing PCS operators to assemble sufficient bandwidth by aggregating 20 MHz assignments, such an approach would slow and make more expensive the initiation of service while reducing significantly

auction revenues. A better method would be to permit 40 MHz assignments to be "dis-aggregated"; that is, to allow licensees of 40 MHz blocs to assign portions of their spectrum to other parties, as appropriate.

Appendix B: Methodological Issues

We should clarify our methodological stance in order that our reasoning, examples, and conclusions can be most usefully understood and applied.[1] Our point of departure is the mathematical theory of games--which the authors have variously studied, taught extensively, and to which we have contributed--yet our analysis and conclusions are not bound by the pure logic of this elegant theory. Instead, our discussion and examples will often invoke additional factors from beyond those traditionally considered in game theoretic analyses. For example, we will consider the likely effects of motivations other than financial such as ego and rivalry among the bidders in other markets, departures from total game-theoretic "rationality" such as the tendency toward counterproductive escalation and the failure to fully anticipate the reactions of other players.

Incidentally, we should be clear that we value economic and game-theoretic insights into auction design; the theory provides a useful benchmark and has already served admirably in helping to analyze the spectrum auction problem. Our reasons for going beyond the traditional theory in the present analysis, however, are partly theoretical, partly empirical, and partly practical, based on substantial non-academic experience. In investigating whether all 20 MHz or some 40 MHz blocks should be auctioned, we believe that it is important and more realistic to consider bidders' motivations, assessments, calculations, reactions, and psychological aspects, that could turn out to be significant in practice--but that might quickly be ruled out by a priori application of stark economic reasoning.

As we work through our reasoning and examples, there may be points at which an orthodox game-theoretic or economic analyst could protest "But that wouldn't be rational! It would never happen that way!" Such objections would have merit if bidders were perfectly calculating, emotionless and monolithic entities with motivations that were entirely economic and did not extend beyond the auction itself--and who were operating within the very carefully defined, self-contained,

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[1]See generally Raiffa, H., The Art and Science of Negotiation, Cambridge, MA: Harvard University Press, Belknap Press, 1982; Lax, D. and Sebenius, J., The Manager as Negotiator, New York: Free Press, 1986; and Sebenius, J., Negotiation Analysis: A Characterization and Review, Management Science 18, 1, January 1992, pp. 18-38.

process that was common knowledge to all participants. Yet to decide whether the objection--"That would never happen; it would be irrational!"--is decisive, we need to understand quite clearly the character of underlying assumptions and their relevance to the actual situation.

First, while we expect bidders to be intelligent, purposive and profit-seeking, we also expect to see significant departures from the exacting requirements of "strategic rationality" in the single-minded pursuit of financial gain within the auction context. Take an simple example, the so-called "ultimatum game" in which one party--the allocator--proposes a division of, say, $100 and the other party--the recipient--decides whether to accept the proposal or not. If the proposal is accepted, then the money is split accordingly; if it is rejected, the game ends and both parties get nothing. (This could be said to correspond to the final stage, for example, of a negotiation.) Rationality and a purely economic motivation suggest the game-theoretic solution for the allocator: offer a penny, which the recipient will take rather than nothing. Anything else would be "irrational" in the most basic sense.

Yet considerable empirical work consistently turns up more complex, seemingly "irrational" ultimatum behavior--a significant percentage of allocators offer much more than a penny, and a significant percentage of recipients reject offers much below an even split.[2] Such "anomalous" behavior has set off a spate of more complex theories--maybe people care about fairness as well or maybe there are reputational issues--but doctrinaire confidence in the narrowly economic "rational" answer, while common, is unwarranted. Our purpose in citing this simple case is not to reject purposeful behavior or the notion of rationality--but instead to widen the range of potential behavior we may expect to see in a setting as complex as high-stakes spectrum auction.

Take a second example familiar to researchers in this field, the "bidding for a company" exercise.[3] Without getting into details, this situation puts bidders in a

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[2]For a recent elaborated example and summary of many related studies, see "Kahn, L. and Murnighan, K., "A General Experiment on Bargaining in Demand Games with Outside Options," American Economic Review, vol 83, No. 5, December 1993, pp. 1260-1280.

[3]For a summary and citations, see Margaret Neale and Max Bazerman, Cognition and Rationality in Negotiation, New York: Free Press, 1991.

situation where making the "rational" bid requires a straightforward inference about the actions of other bidders. Empirically, only a small fraction of bidders get it right--even for a range of quite experienced subjects, playing repeatedly for real money, and with direct computer feedback that should enable them to learn from and correct their (often losing) strategies. (This failure to adjust in advance by making an inference about the actions of others aligns with empirical studies of bidding for items from offshore oil tracts to baseball players.)

If predicting behavior in these two very simple situations is resistant to straightforward economic reasoning, then we urge caution in using similar reasoning to predict (or rule out) behavior in vastly more complex spectrum auctions. After all, there is a range of well-documented systematic cognitive deviations from strict rationality, commitments to unproductive escalation, as well as other seeming anomalies.[4] Robert Campeau's astronomical and bankruptcy-inducing bid for Federated Department Stores comes to mind as does the recent Paramount-Viacom-QVC battle. Felix Rohatyn, Paramount's investment banker and veteran of many bidding contests over the last few decades, remarked "Most deals are fifty percent emotion and fifty percent economics."[5]

Add to these factors the tremendous structural uncertainty and very rapid change in how the market for PCS will shake out. Different players have very different, often incompatible, motivations and visions of the future of this industry. As such, it will be extremely difficult for some of the most basic requirements of

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[4] See, e.g., Neale and Bazerman, Cognition and Rationality in Negotiation, New York: Free Press, 1991; Einhorn and Hogarth, Behavioral Decision Analysis: Processes of Judggment and Choice, in D.E. Bell, H. Raiffa and A. Tversky (eds.), Decision Making: Descriptive, Normative and Prescriptive Interactions, Cambridge University Press, Cambridge, 1988; along with the other excellent collections of papers in Kahneman, Slovic, and Tversky, Judgment Under Uncertainty: Heuristics and Biases, Cambridge University Press, Cambridge, 1982; the review in Schoemaker, The Expected Utility Model: Its Variants, Purposes, Evidence and Limitations, Journal of Economic Literature 20, 1983, pp. 529-563;, and Bell, Raiffa and Tversky (eds.), Decision Making: Descriptive, Normative and Prescriptive Interactions, Cambridge University Press, Cambridge, 1988.

[5] New Yorker, October 4, 1993, p. 80.

strict game analysis to hold; in particular, many features of the situation will not be "common knowledge" to the players.[6]

This methodological discussion carries two important implications for the discussion and analysis that follow. First, in comparing auctions with and without 40MHz blocks, we will be discussing what actions and outcomes are likely to be realistically plausible--not only what is narrowly "rational" in a game sense. Our examples will contain some of what might be labeled "irrationalities;" the test of their value should be a test of their plausibity. Second, confident predictions of a smoothly functioning, efficient secondary market that will correct any allocation problems from the auction stage must be viewed with similar skepticism. Such markets will likely consist of small numbers of players, some of whom will compete and/or cooperate in many other markets. For many of the reasons cited above, there does not now exist a satisfactory theory of coalitional action to confidently predict negotiated outcomes in such settings.

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[6]As the pre-eminent game theorist Aumann unequivocally concluded, "*The common knowledge assumption underlies all of game theory and much of economic theory. Whatever be the model under discussion, whether complete or incomplete information, consistent or inconsistent, repeated or one-shot, cooperative or non-cooperative, the model itself must be assumed common knowledge; otherwise the model is insufficiently specified, and the analysis incoherent.*" (emphasis supplied). See Aumann, R. J. (1989:31). Game Theory. In J. Eatwell, M. Milgate, and P. Newman (Ed.), Game Theory (pp. 1-53). New York: Norton.